Wind Program Performance Tracking

"Technology Characterization and All Its Uses"

For Wind Program Implementation Meeting

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Broomfield, CO

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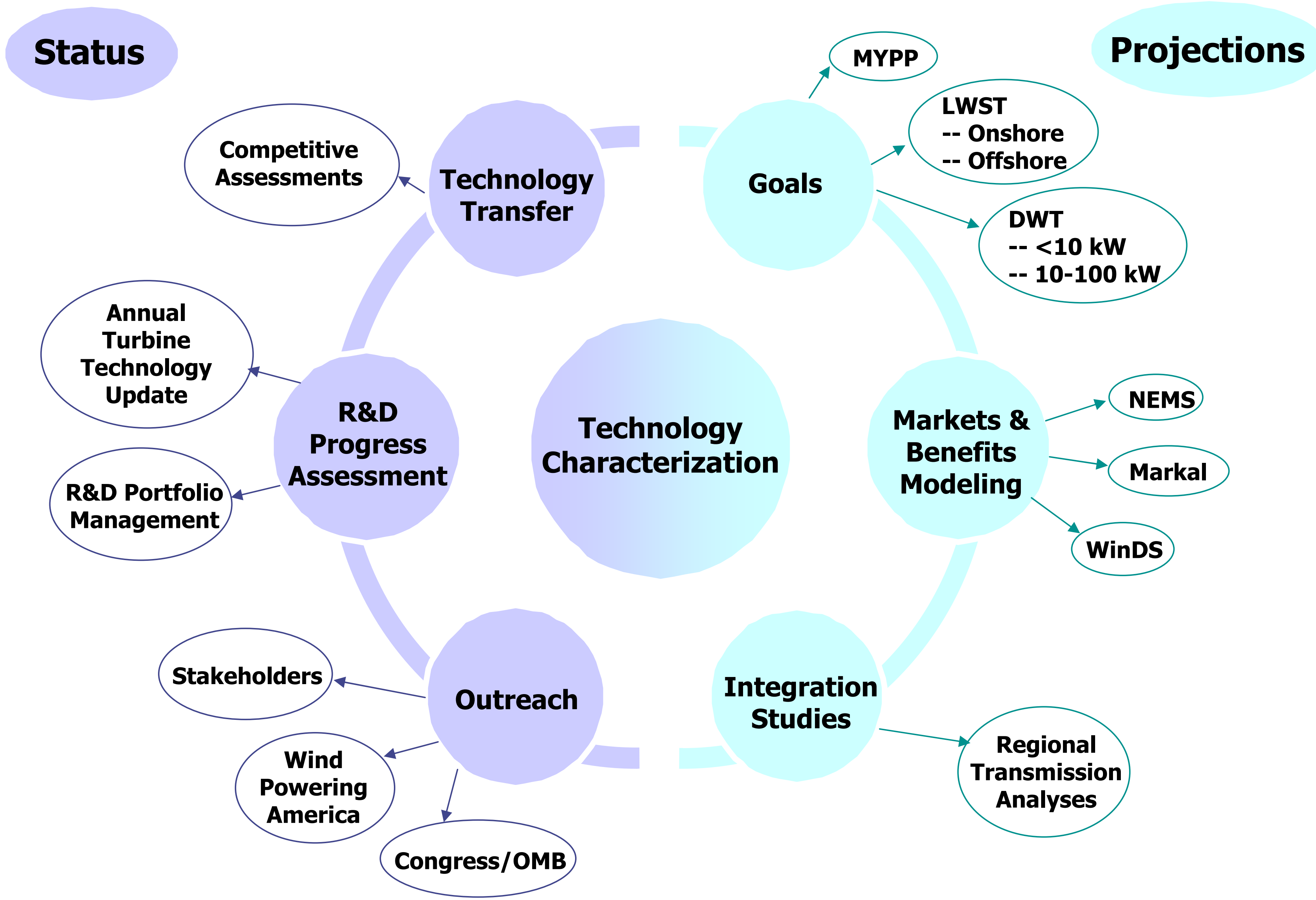
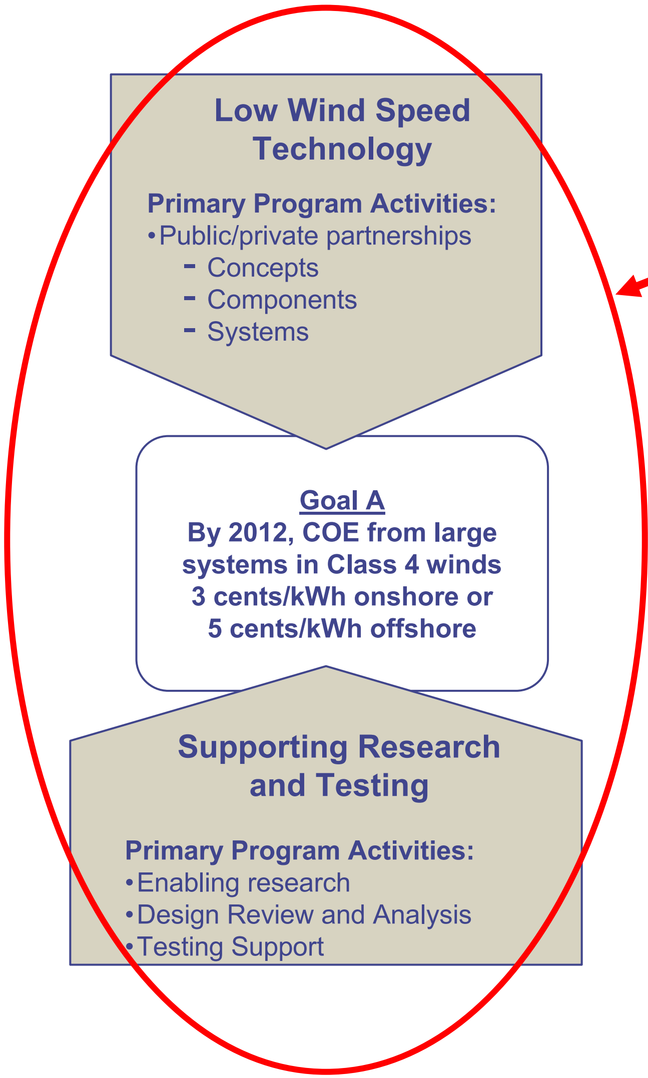
Technology Characterization Is Key

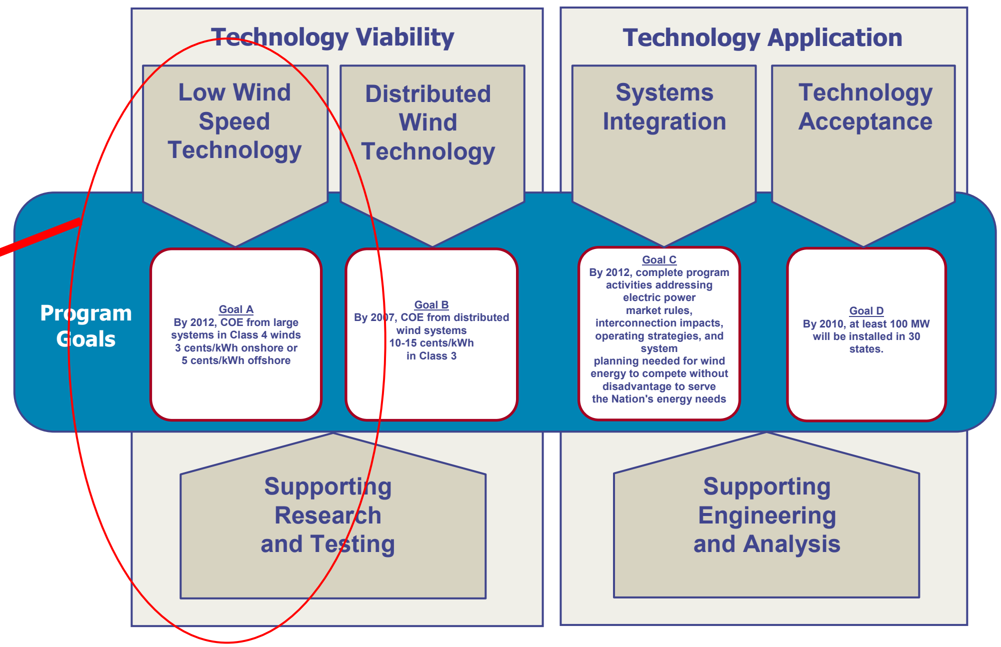


Program Structure and Goals

Focus of this talk



Overall Program Structure



Two Elements of Low Wind Speed Technology (LWST) Program Planning

Pathway(s) Analysis

- Characterization of Reference Turbine
- LWST Goals
- Technology Improvement Opportunities (TIOs)
- Wind Pathways (Monte Carlo) Model

Portfolio Assessment

- Annual Turbine Technology Update (ATTU)
- Yearly LWST (subcontract) Portfolio Assessment
- Yearly SR&T (lab) Portfolio Assessment

LWST Goals and Performance Tracking

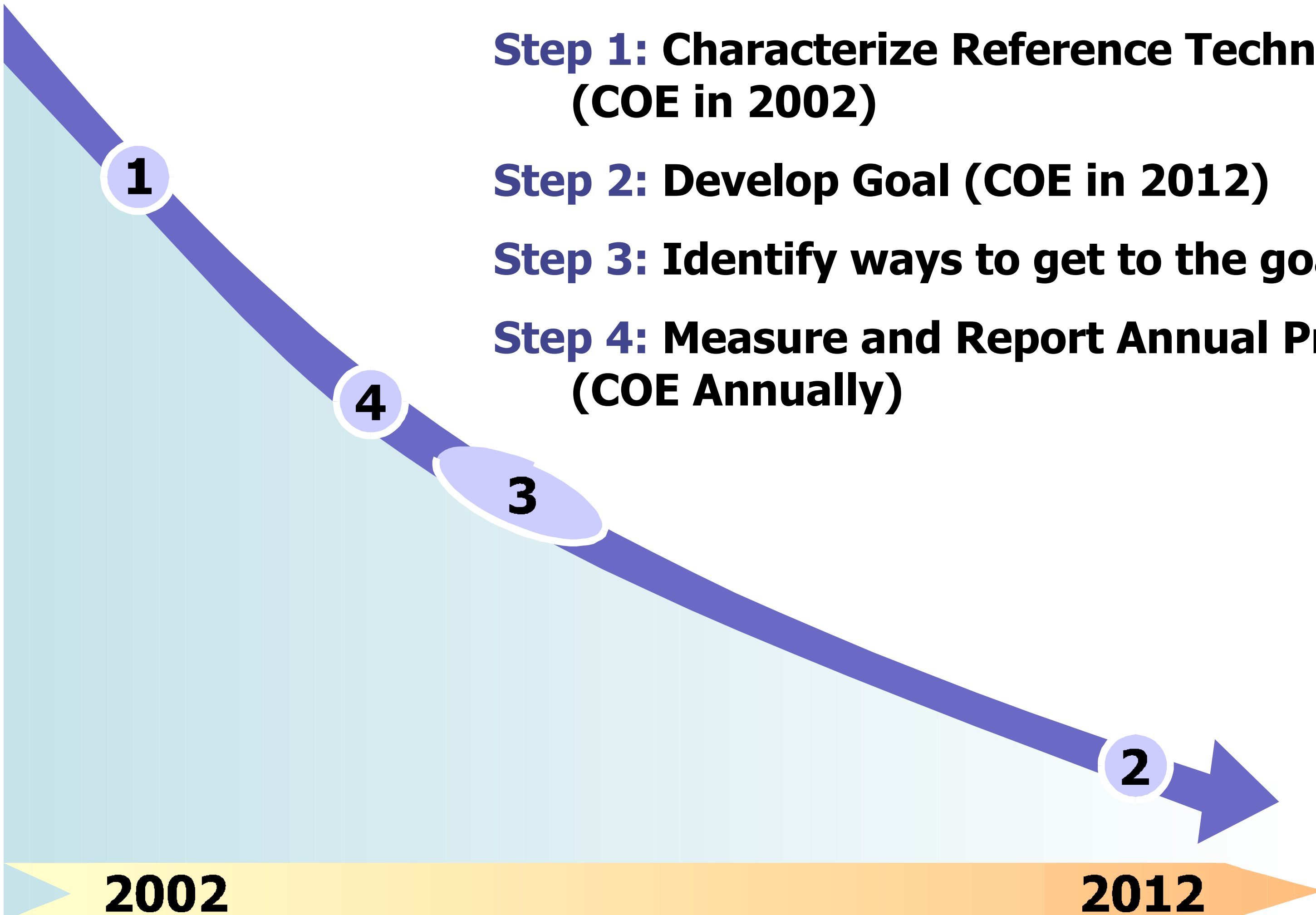
Performance Measurement is a Four Step Process:

Step 1: **Characterize Reference Technology (COE in 2002)**

Step 2: **Develop Goal (COE in 2012)**

Step 3: **Identify ways to get to the goal**

Step 4: **Measure and Report Annual Progress (COE Annually)**



Step 1: Characterize Reference (2002) Technology

Reference Turbine is a composite:

From DOE-sponsored WindPACT studies (2002) and market data, based on 100 MW of installed experience

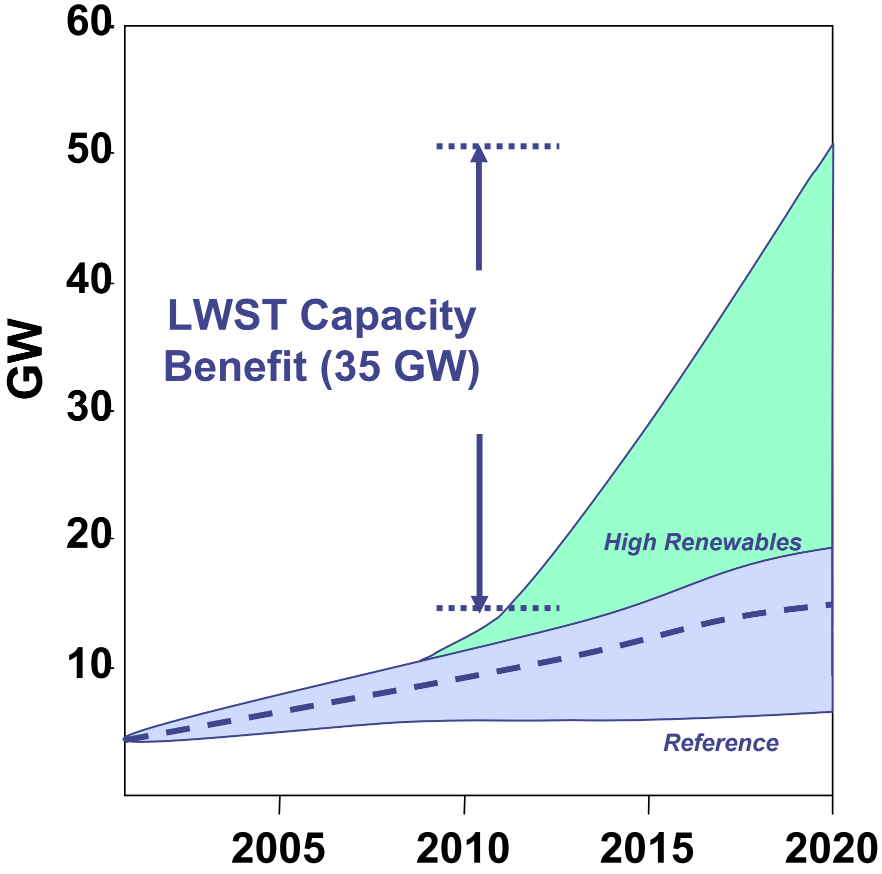
Levelized Cost of Energy of Reference (2002) Turbine: 4.8 cents/kWh

The "fine print":

- In constant end-of-2002 dollars
- Class 4 winds (5.8 m/s average at 10 m)
- Assumes financing structures typical of GenCos (i.e., balance sheet financing)
- Detailed cash flow model used to calculate COE using assumptions for taxes, insurance, depreciation, cost of capital, financing fees, and construction financing
- 30-year project lifetime
- Caveat – uses a relatively high required rate of return compared to current market rates

Step 2: Develop Goal (2012)

- Goal-setting is often a balance between identifying what is needed for success in the marketplace and what is technically possible
- An LWST goal of 3 cents/kWh was attractive:
    - An additional 35 GW of wind by 2020
    - Expands resource base 20-fold
    - Reduces average distance to load 5-fold
- However, the question remained – is 3 cents/kWh possible?



Blue area represents range of EIA/AEO 2001 Renewables Cases

Step 3: Is 3 cents/kWh achievable in Class 4 winds?

Analysis Process

Identify TIOs → Estimate TIO Effects → Perform Analysis → Review Results

Step 1: Identify a "menu" of Technology Improvement Opportunities (TIOs) that could lead to this improvement

Step 2: Estimate the range of potential change in cost, performance, reliability, and O&M for each TIO category

Step 3: Run these through a turbine systems model (the "Pathways Model") to assess impact on COE

Step 4: Produce a curve of COE versus likelihood of achieving it.

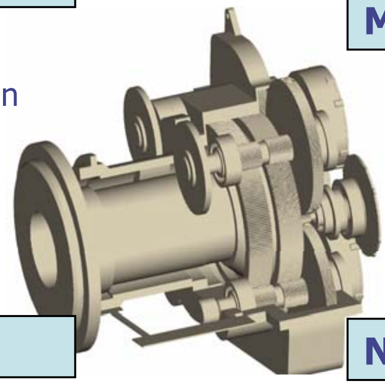
Data Sources

NREL/Sandia staff, WindPACT studies, Next Generation Turbine project, LWST proposals, in-house knowledge, etc.

Technology Improvement Opportunities (TIOs)

Advanced (Enlarged) Rotor TIOs

- Advanced materials
- Changed/improved structural/aero design
- Active controls
- Passive controls
- Higher tip speed ratios/lower acoustics



Site-Specific Design/Reduced Design Margin TIOs

- Improved definition of site characteristics
- Design load tailoring
- Micrositing
- Favorable wind speed distributions and shear

Manufacturing TIOs

- Manufacturing methods
- Lower margins
- Manufacturing markups

New Drive Train Concept TIOs

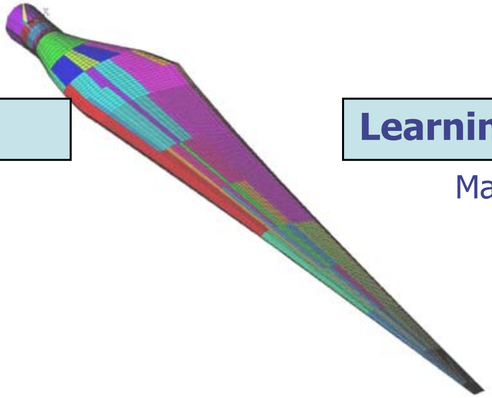
- Permanent magnet generator
- Innovative mechanical drives

Reduced Energy Losses and Increased Availability TIOs

- Health monitoring (SCADA, etc.)
- Blade soiling mitigation
- Extended scheduled maintenance

Advanced Power Electronics TIOs

- Incorporation of improved PE components
- Advanced circuit topology



Advanced Tower TIOs

- New Materials
- Innovative structures
- Advanced foundations
- Self-erecting designs

Learning Curve Effects

- Market–driven cost reductions

Initial Screening: Impact of TIOs on Elements of COE

COE α Cost/Energy + O&M + Replacements

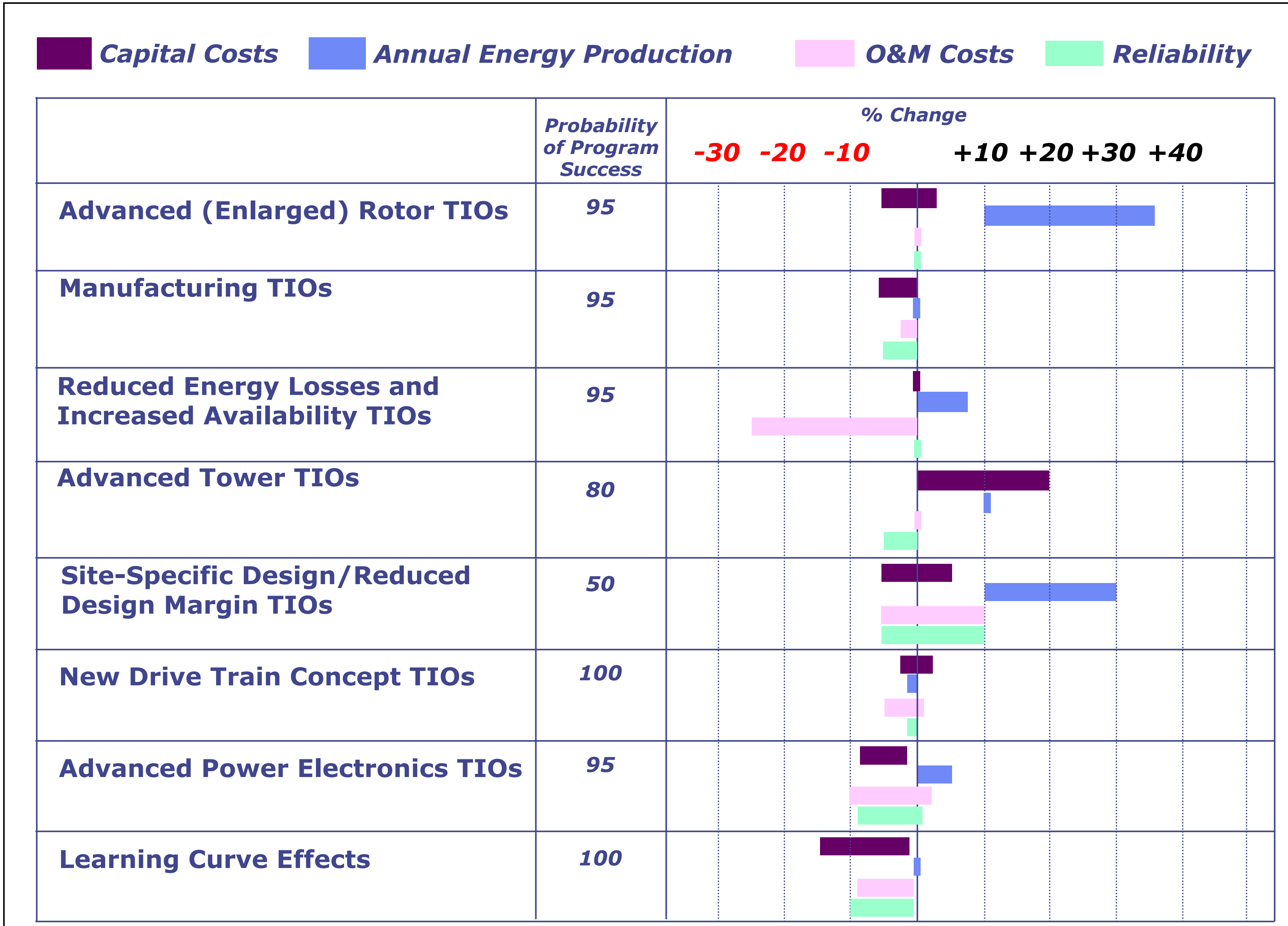
Impacts

Large	
Moderate	
Small	

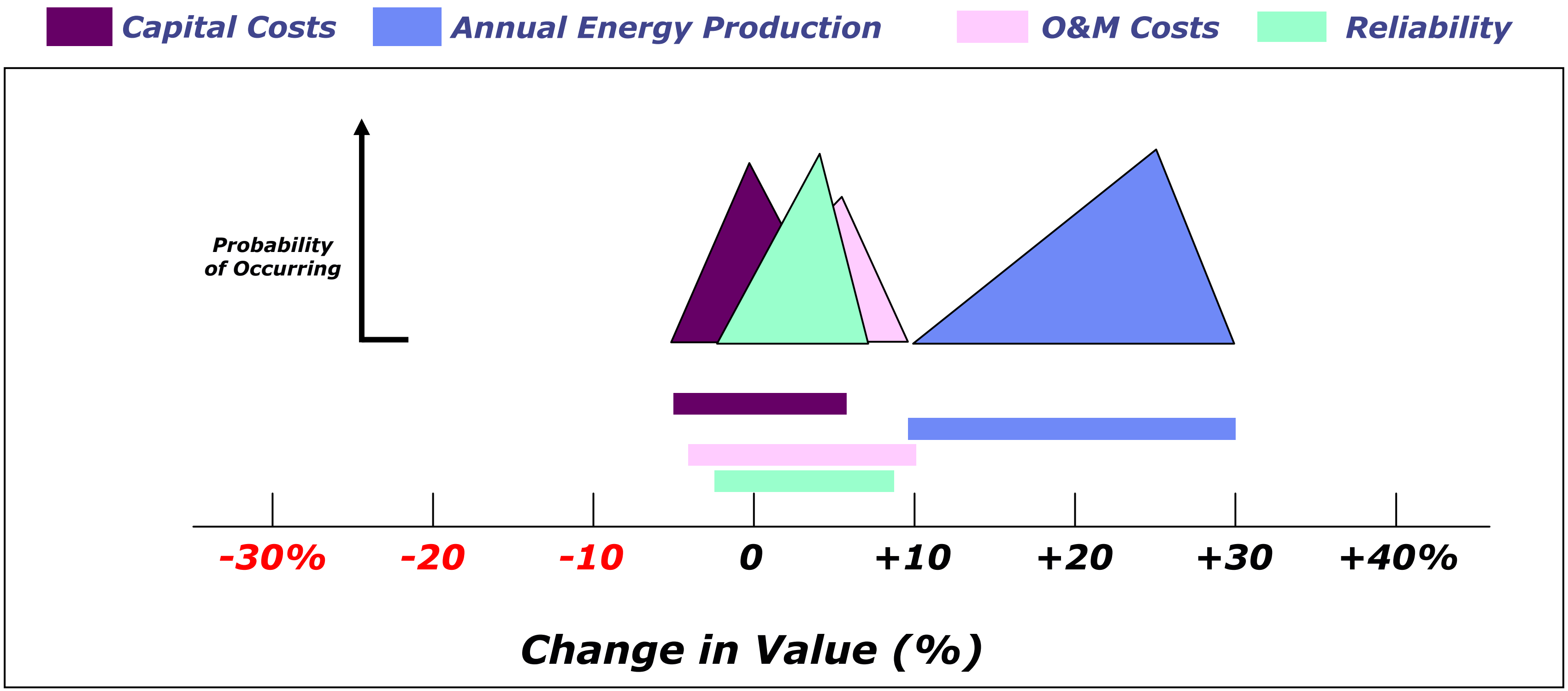
TIO Categories

		Cost	Energy Production	O&M Cost	Reliability/ Replacements
Advanced (Enlarged) Rotor	Advanced materials				
	Changed/improved structural/aero design				
	Active controls				
	Passive controls				
	Higher tip speed ratios/lower acoustics				
Manufacturing	Manufacturing methods				
	Lower margins				
	Manufacturing markups				
Reduced Energy Losses and Increased Availability	Health monitoring (SCADA, etc.)				
	Blade soiling mitigation				
	Extended scheduled maintenance				
Advanced Tower	New Materials				
	Innovative structures				
	Advanced foundations				
	Self-erecting designs				
Site-Specific Design/Reduced Design Margin	Improved definition of site characteristics				
	Design load tailoring				
	Micrositing				
New Drive Train Concepts	Favorable wind speed distributions and shear				
	Permanent magnet generator				
	Innovative mechanical drives				
Advanced Power Electronics	Incorporation of improved PE components				
	Advanced circuit topology				
Learning Curve Effects	Market-driven cost reductions				

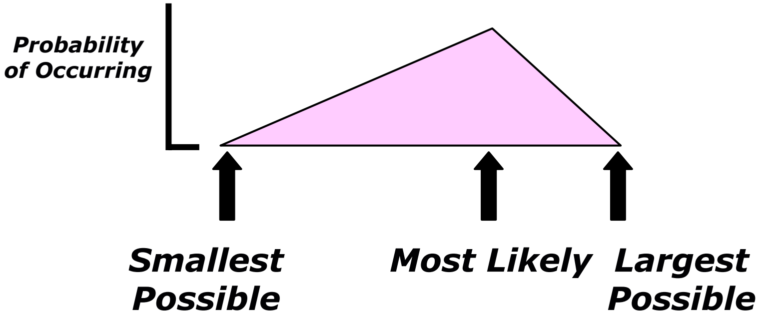
TIOs' Potential for Improvement
(% change from reference turbine and probability of program success)



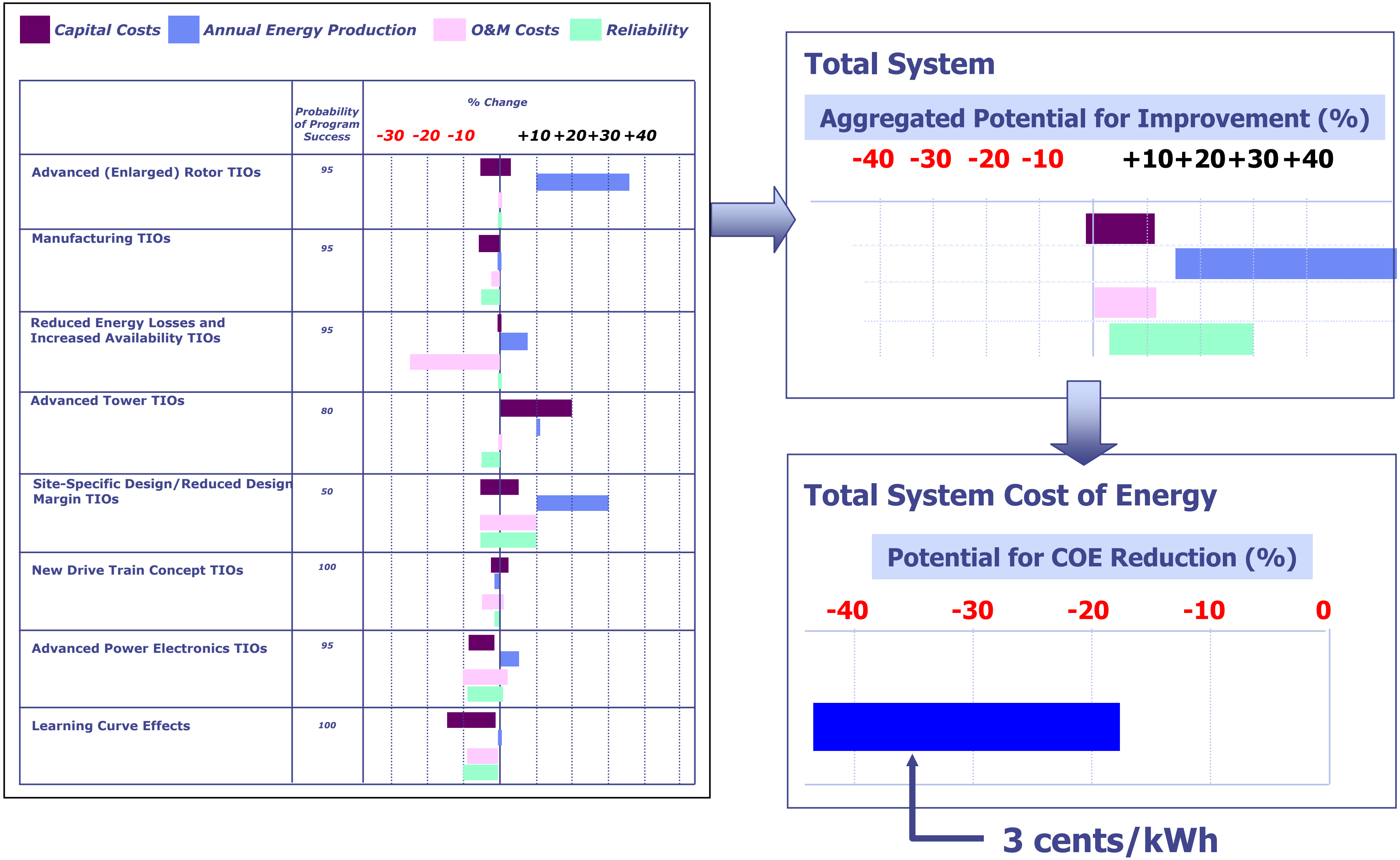
Example: New Drive Train Concept TIOs



The Ranges for Each TIO Are Really Distributions of Impacts

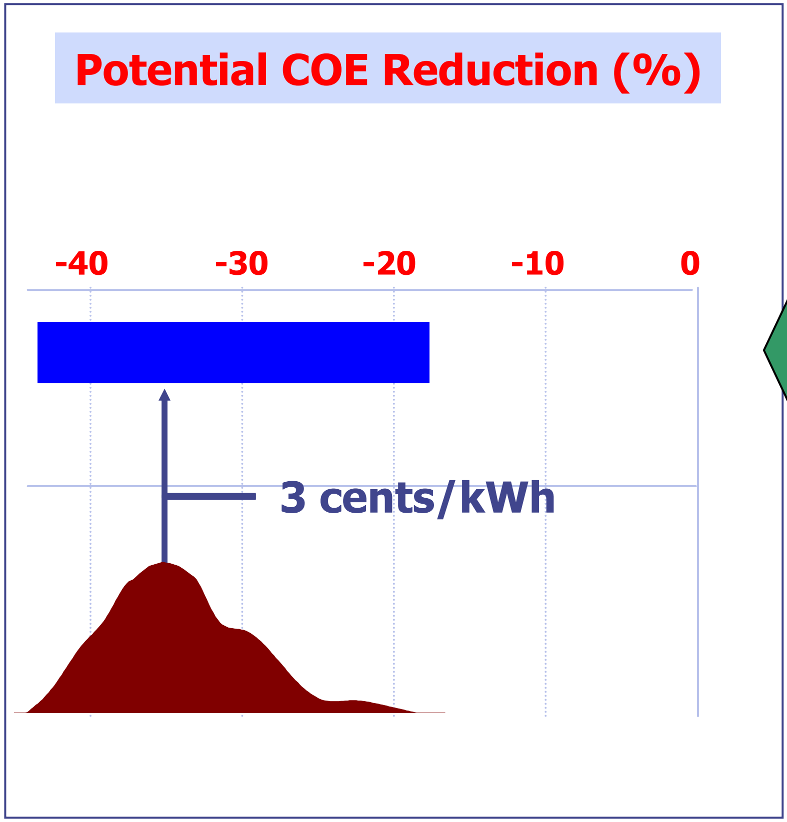


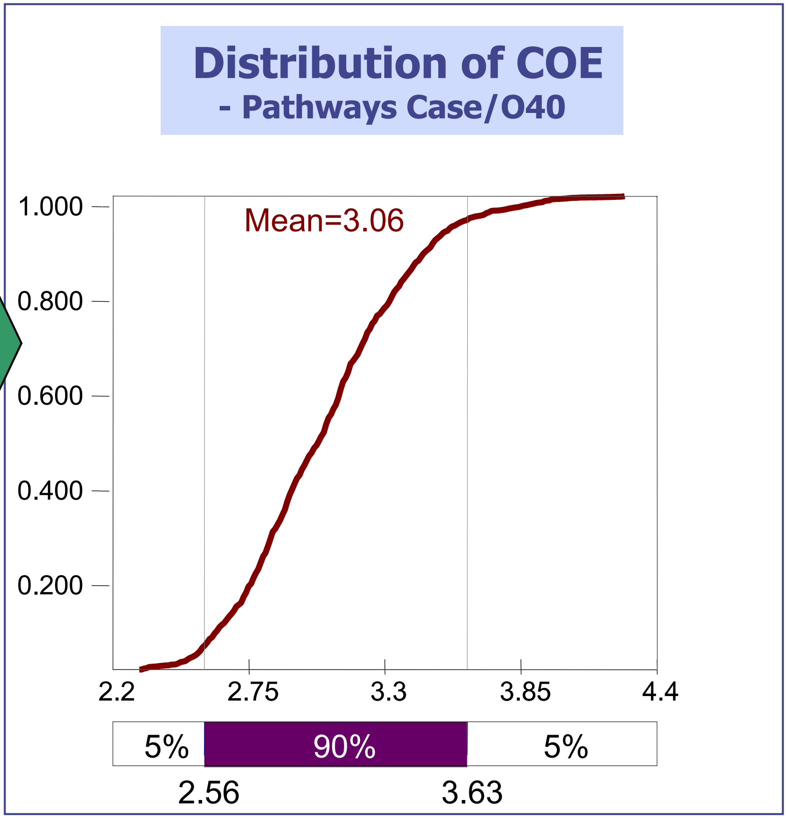
Wind Technology Pathways Model
(A Monte-Carlo Wind Turbine Analysis Tool)



Total System Cost of Energy

The COE can be expressed as a Cumulative Probability Distribution, to quantify the certainty of the COE outcome



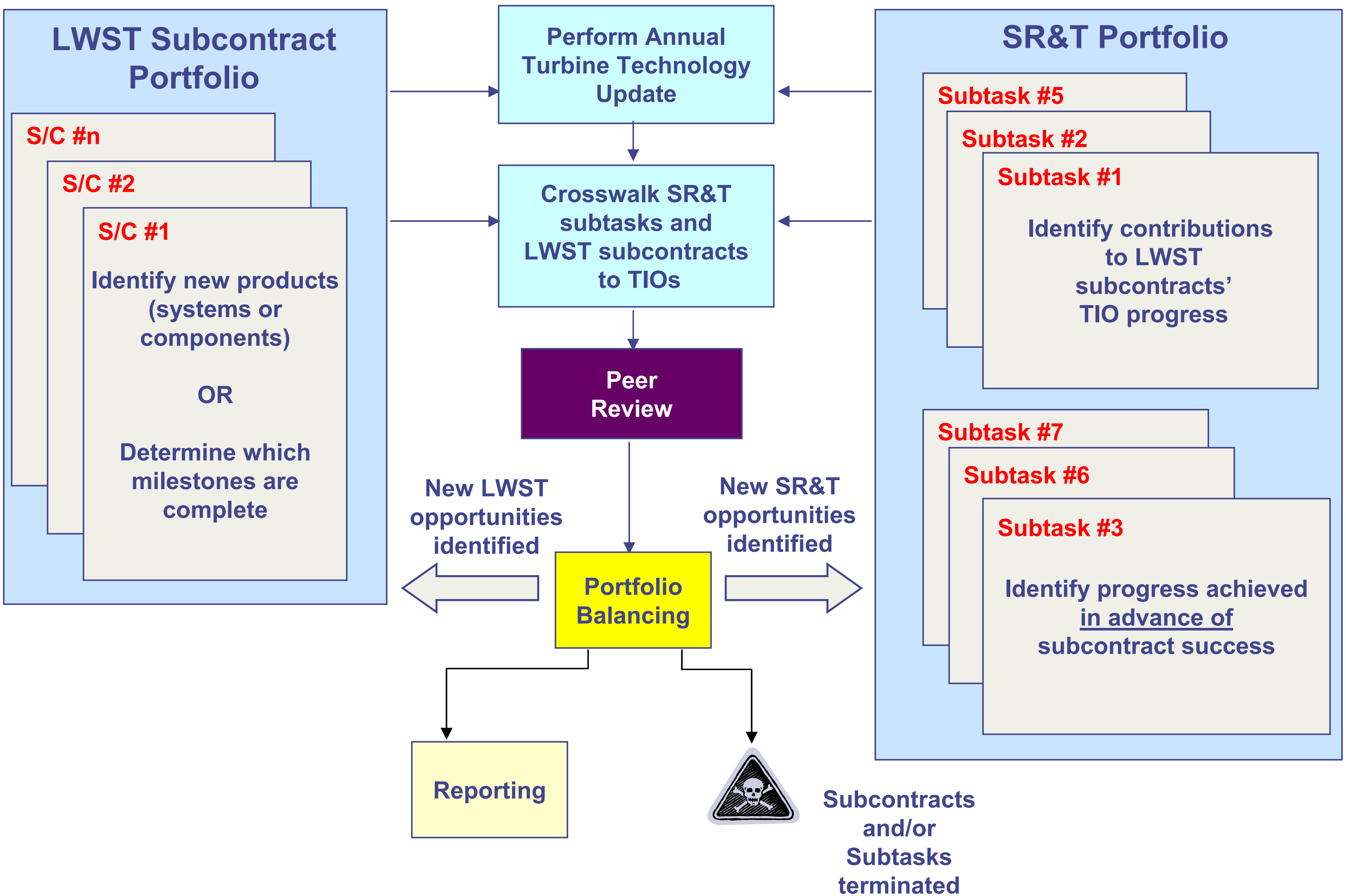


Step 4: Reporting Annual Progress

Annual assessment of progress takes many forms:

- Annual Turbine Technology Update for LWST program
- Reporting for other program elements (DWT, Systems Integration, and Technology Acceptance)
- Milestone tracking – both at task level and programmatic level
- Peer review process
- Government Performance and Results Act (GPRA)

Annual LWST Portfolio Assessment Process



Tracking COE Progress: the "Annual Turbine Technology Update"

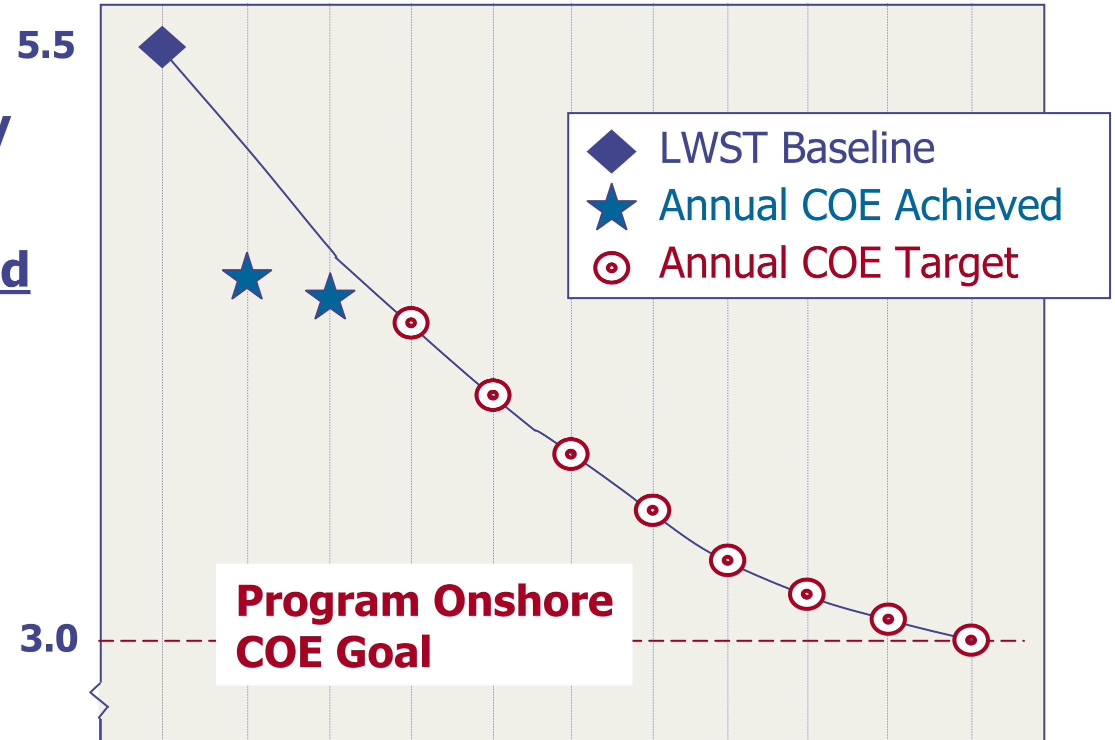
The Annual Turbine Technology Update is the Program's formal process for reporting LWST progress

- In some years, the Program may actually have a new turbine to point to for the Annual Turbine Technology Update process
- In other years, may have to build a "virtual turbine" based on component progress, interim prototype progress, SR&T progress, etc.
- Expert judgment required; program will draw on an expert panel for evaluation

LWST Program Performance Reporting
(Status as of end of 2004)

- **In 2002, LWST program postulated a COE trajectory that would lead to the goal**
- **The program must track <u>and report</u> annual progress against that trajectory**

Cost of Energy (cents/kWh)
(End of year, at Class 4 sites, levelized in 2002$)



(in cents/kWh)	2002		2004		2006			2008		2010		2012
LWST Project Targets	5.5	5.0	4.6	4.3	4.0	3.7	3.5	3.3	3.2	3.1	3.0	
ATTU	4.8*	4.5	4.4									

**ATTU Reference Turbine*

The 2003 “Annual Turbine Technology Update”

- For 2003, program had a new turbine

  -- a 70-m diameter design that evolved to 77 m

- This results in a levelized COE of 4.5 cents/kWh (2002$) – a 0.3 cent/kWh reduction from the reference turbine

The Advanced Rotor TIO was primary contributor to COE reduction in FY2003; others contributed less

TIO Category Contribution to 2012 Goal

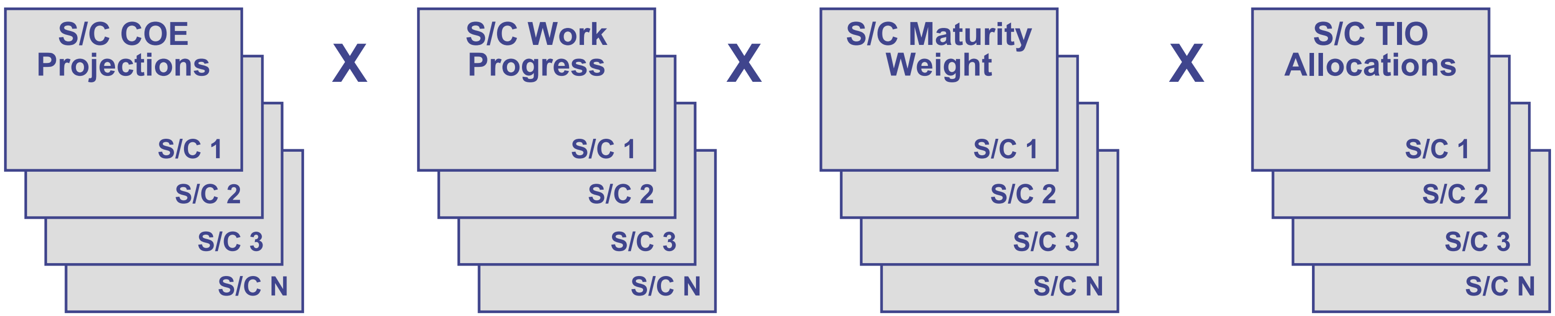
	Cost	Energy Production	O&M Cost	Reliability
Advanced (Enlarged) Rotor	Moderate	Large	Small	Small
Manufacturing	Large	Small	Small	Large
Reduced Energy Losses and Increased Availability	Small	Large	Large	Large
Advanced Tower	Large	Large	Small	Moderate
Site-Specific Design/Reduced Design Margin	Moderate	Large	Moderate	Moderate
New Drive Train Concept	Moderate	Moderate	Large	Moderate
Advanced Power Electronics	Moderate	Moderate	Moderate	Moderate
Learning Curve Effects	Large	Small	Moderate	Moderate

Long-term potential impact: Large (red) **Moderate** (yellow) **Small** (white)

The 2004 “Annual Turbine Technology Update”

- In 2004, there were no new turbine systems to point to
- Program used “virtual turbine” process where on-going LWST subcontracts were examined for their progress in meeting their individual TIO potential
- A small COE reduction of 0.1 cents/kWh was inferred from the year’s activities

Virtual Turbine Process for the "Annual Turbine Technology Update"



- **Each subcontract projects a COE improvement**
- **Stage gate progress of each subcontract is assessed**
- **Conceptual designs are weighted less than prototypes**
- **A project's COE reduction can be from more than one TIO**

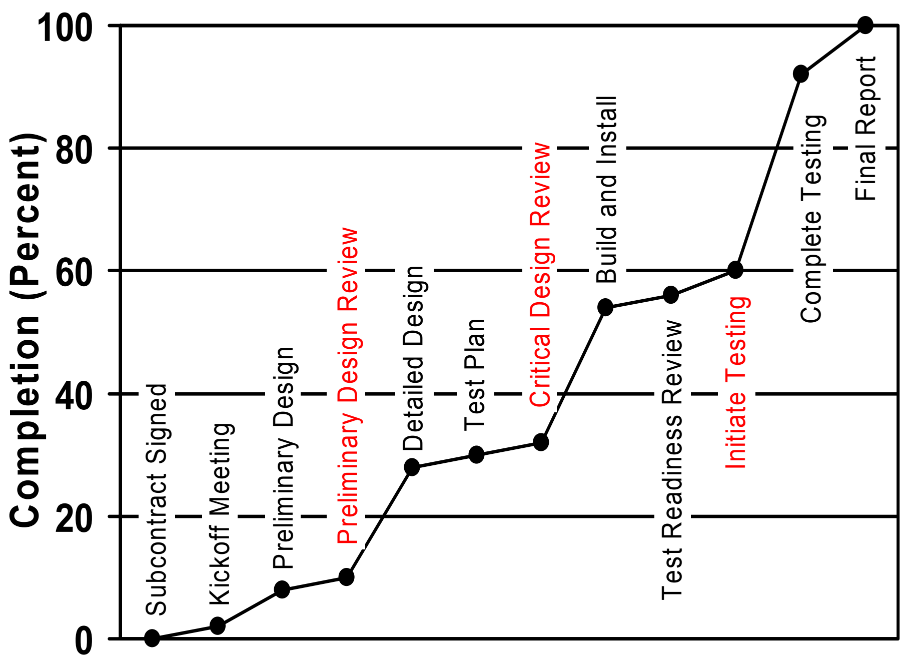
	TCC	BOS	LRC	O&M	AEP
TIO 1					
TIO 2					
TIO 3					
TIO 4					
TIO 5					
TIO 6					
TIO 7					
TIO 8					

Percent Improvements

Annual COE Reduction Achieved

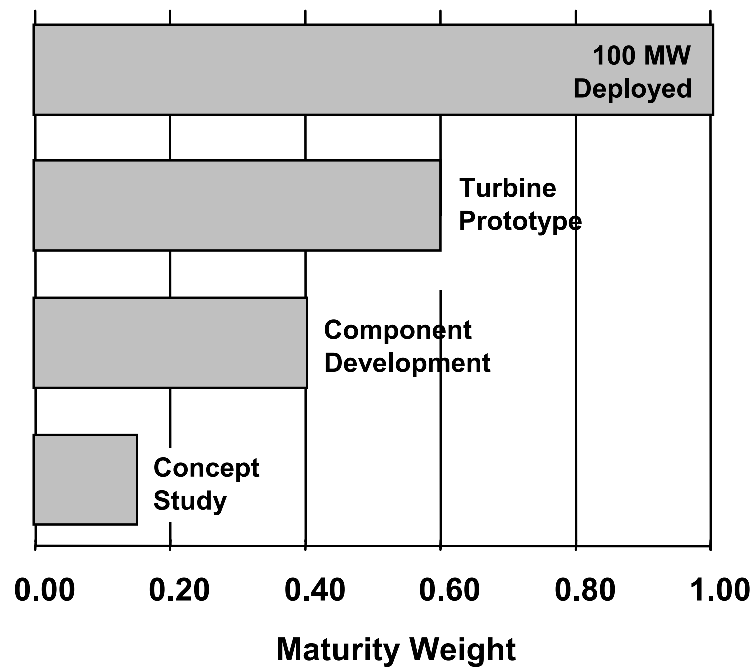
Details on Virtual Turbine Process for the "Annual Turbine Technology Update"

Stage Gate Process Assessment



Red = Stage Gate

Weighted Value of Effort



- Stage gate = key S/C progress control point
- Varies with individual subcontract

- Note – greatest value is only achieved with substantial commercialization (100 MW deployed)

2003 Wind Program Portfolio Assessment

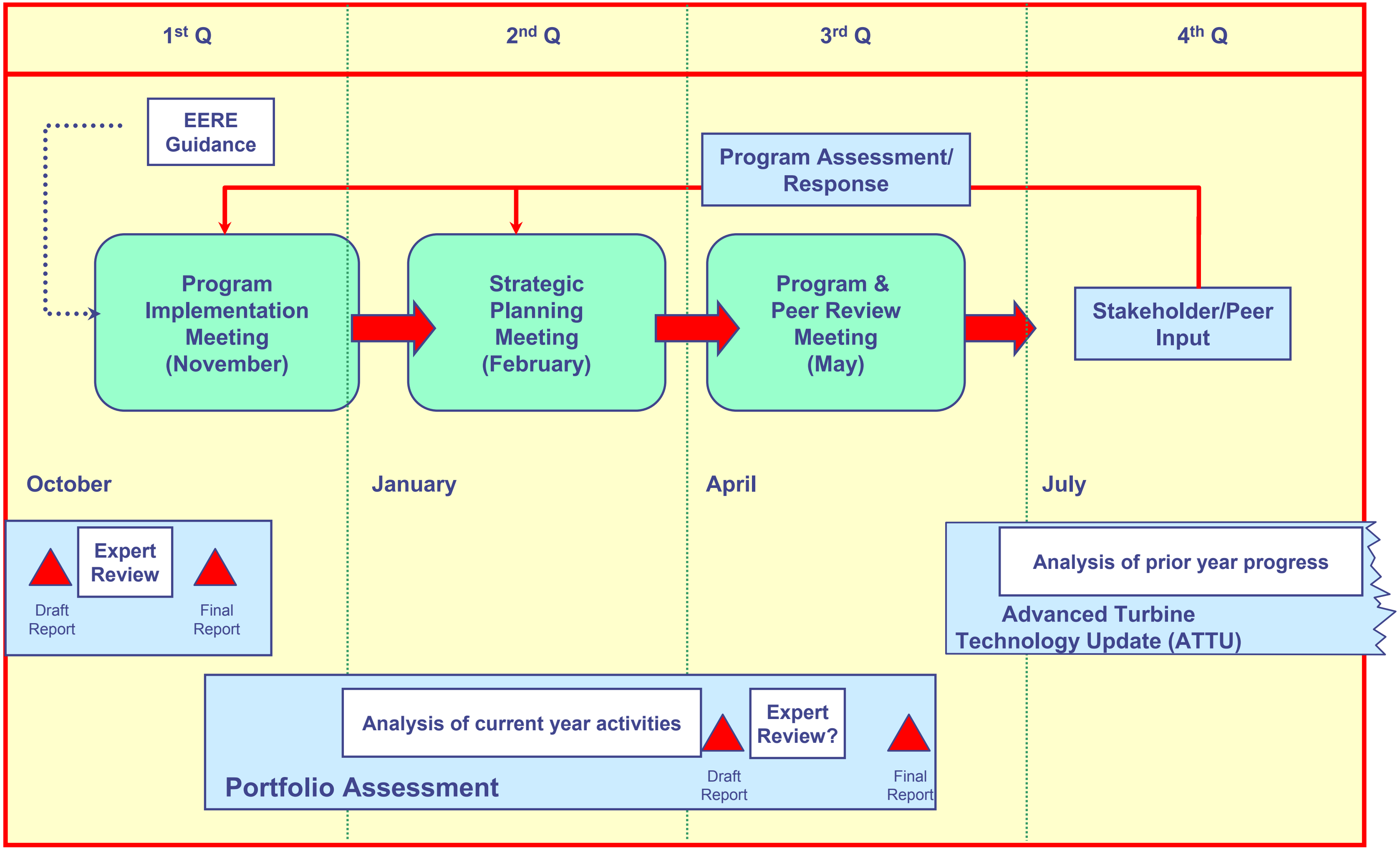
Impact:

High	H
Moderate	M
Low	

Technology Improvement Opportunities (TIOs)		LWST & DWT Subcontracts									SR&T Research Tasks											
		LWST & DWT Subcontracts									**Advanced Rotor Development**										**Blades**	
		Clipper Windpower - Quantum Turbine	GE Wind - Multi-Megawatt Turbine	Northern Power Systems - Generator drive train development - Direct Drive	Global Energy Concepts - single Stage Drive/Medium Speed Generator	Northern Power Systems - Advanced Power Electronics	Advanced Energy Systems - Independent Blade Pitch Control	Berger/ABAM - Steel/Concrete Hybrid Towers	GEC - Blade Study	TPI - Blade Study	Aerodynamics Model Development	Aerodyn State Space Model Development	Unsteady Separated Flow Research	CFD Aerodynamic Analysis (NAU)	IEA Annex XX Initiative	Aeroacoustics Model Development	Rotor Load Control Strategies	Hinged Rotor Technology Assessment	Advantek; Rotor Control CRADA	3M; Blade Coating CRADA		Adaptive Structures
	Number of Years	3	3	2																		
	Current Year Funding	5	5	1																		
	Total Required Funding	15	15	2																		
Advanced (Enlarged) Rotor	Advanced materials	M	H																	H		
	Changed/improved structural/aero design	H	H				M				H	H	H	H	M	M	H	H	H			M
	Active controls	M	M				H				H	H	H		M		H	H	H			H
	Passive controls		M								H	H	H		M		M		H			H
	Higher tip speed ratios/lower acoustics		M								H	H	H	H	M	H						M
Manufacturing	Manufacturing methods		H						H	M												
	Lower margins								M	M												
	Manufacturing markups								H													
Reduced Energy Losses & Increased Availability	Health monitoring (SCADA, etc)		M																			M
	Blade soiling mitigation																			H		
	Extended scheduled maintenance		M																			
Advanced Tower TIOs	New Materials							M														
	Innovative structures							H			M	M										
	Advanced foundations							M			M	M										
	Self-erecting designs							M			M	M										
Site-Specific Design / Design Margin Reduction	Improved definition of site characteristics																					
	Design load tailoring										H	H					H					
	Micrositing										H	H					H					
	Favorable wind speed distributions and shear										H	H					H					
Drive Train Concepts	Permanent magnet generator	H		H	H																	
	Innovative mechanical drives	H		H																		
Advanced Power Electronics TIOs	Incorporation of improved PE components	M	H	H		H																
	Advanced circuit topology	H			M	H																
Learning Curve Effects			M		M				M	H												

Process is Now Being Used

- Fully integrate portfolio assessment and progress reporting into wind program management cycle



Wind Energy Program Multi Year Program Plan: 2005-2010

New version just released

What Does the Future Hold for Performance Tracking?

- PERI is working with EERE management staff (the Wind Program's "front office") to enhance the TIO uncertainty analysis process and adapt it for use in its other programs
- We are working to produce detailed documentation of the wind program's COE methods and of how program COEs relate to industry COEs
- We are preparing a series of reports on the wind Technology Characterization work
- We are working with NREL to better understand the national and regional benefits of deep-water offshore deployment and of ways to include offshore in the National Energy Modeling System (NEMS)